An Experimental Apparatus for Drying Particulate Foods in Air

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SUMMARY

An apparatus is described which can be used to study through-circulation air drying of particulate foods at low and moderate temperatures. As an "atmospheric freeze-dryer" a dew-point temperature of −80°F can be attained at a dry-bulb temperature between 20°F and 32°F. With the dry-bulb temperature between 32°F and 160°F, the dew-point temperature can be controlled between 0°F and 80°F. Air rate can be controlled between 100 and 300 standard cubic feet per min.

INTRODUCTION

Forced-circulation air drying of fruit and vegetable pieces has been little explored using moderate to low air temperatures and low humidities. The only operations reported in these areas have been the Birs-Hussman spray drying process which uses desiccated air of temperature between 64°F and 86°F (Lang, 1964; Ziemba, 1962), and the so-called "atmospheric freeze-drying" process which uses desiccated air of temperature less than 32°F (Lewin *et al.,* 1962; Meryman, 1959; Woodward, 1963). Since foods dried by these methods have been reported to be of good quality, there apparently exist good possibilities for preparing unique dehydrated foods through air drying.

The purpose of this report is to describe a unit designed to study the dehydration of fruit and vegetable particulates under these conditions. The ranges of the process variables were extended to also cover more common hot air drying conditions.

SPECIFICATIONS

A system was envisioned in which air would be moved at a desired rate by a variable speed blower through a section where the dew-point temperature would be fixed, through another section where the dry-bulb temperature would be fixed, through an experimental dryer where the air could be directed either up or down through a bed containing fruit or vegetable pieces, and finally back to the blower.

For clarity in drawing up the specifications the system was presumed to operate either as an "atmospheric freeze-dryer," or as a dryer operating above 32°F dry-bulb temperature. When operating as an "atmospheric freeze-dryer" all of the air would pass through a desiccant column and its dew-point temperature on leaving the column would be −80°F. When operating above 32°F dry-bulb temperature the dew-point temperature would be automatically controlled and recorded at any temperature between 0°F and 80°F. The dry-bulb temperature would be automatically controlled and recorded at any temperature between 20°F and 160°F and the air rate would be adjustable to any value between 100 and 300 standard cubic feet per min (SCFM).

The minimum water vapor capacity of each desiccant column between regenerating cycles was set at 17 lb. This corresponds to the moisture contained in a bed of ⅜ in. potato dice 1 sq ft in area and 6 in. deep. The maximum evaporation rate under "freeze-drying" conditions was estimated to be 0.05 lb of water per min (32°F dry-bulb, 300 SCFM air rate, −80°F dew-point), and under "non-freeze-drying" conditions it was estimated to be 0.33 lb of water per min (160°F dry-bulb, 300 SCFM air rate, 0°F dew-point). The dry-bulb temperature was to be controlled to within ±2°F, and the dew-point temperature was to be controlled to within ±1½°F.

EQUIPMENT

Fig. 1 shows the general arrangement of the apparatus. The air stream leaves the variable speed blower in 4 in. aluminum tubing and arrives first at the section where its dew-point temperature is fixed. This is done automatically or manually by the dew-point control system, which splits the stream into a part that passes through a desiccant column and a part that by-passes it. The stream merges and leaves the dew-point section at the desired dew-point temperature. (Fig. 1 depicts desiccant column #2 on-stream and desiccant column #1 on regeneration.)

The air stream then enters the section where its dry-bulb temperature is fixed. This is done automatically by

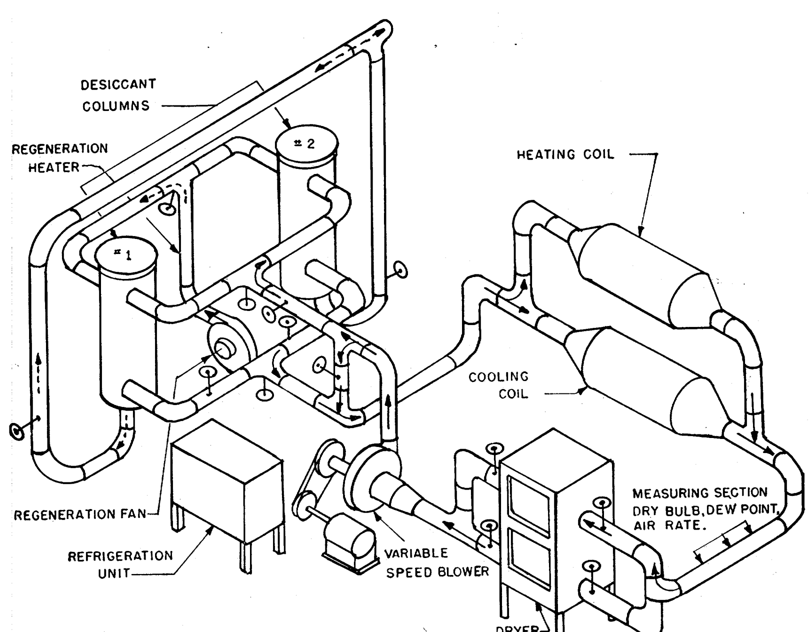

Fig. 1. General arrangement of the experimental apparatus.

the dry-bulb control system, which splits the stream into a fraction that passes through a cooling coil and a fraction that passes through a heating coil. On merging again the air stream passes through a section where its rate, dry-bulb and dew-point temperatures are measured. The air then reaches the experimental dryer where it can be passed either up or down through a bed of fruit or vegetable pieces by appropriately setting four butterfly valves. The air stream then returns to the blower.

The blower is driven by a 5 HP, 1750 rpm motor through a variable speed pulley. It is rated to deliver a maximum of 360 SCFM of dry air (70°F and 1 atmosphere pressure) at a developed pressure of 48.4 in. of water. The desiccant columns each contain 900 lb of 4-mesh anhydrous $CaSO_4$ rated to absorb 45 lb of water. The usual operation is to set hand valves to put one column on-stream while the other column is being regenerated automatically by a sequence timer. It is possible, however, to have both columns on-stream operating in parallel. This feature is useful in instances where a low humidity is needed, but an initial evaporation rate greater than the design criteria is expected.

Regeneration is accomplished by hot air. The regeneration fan picks up ambient air, moves it through electric heating rods (not shown) where its temperature is raised to about 500°F, through the bed of desiccant, and then to exhaust. After 4 hr of heating, during which time the temperature of the bed has been raised to above 400°F, the electric rods are automatically shut off and cooling water begins to circulate through a copper coil immersed in the bed. After the fifth hour, the regeneration fan automatically shuts off, and after the eighth hour the cooling water automatically shuts off, completing the cycle.

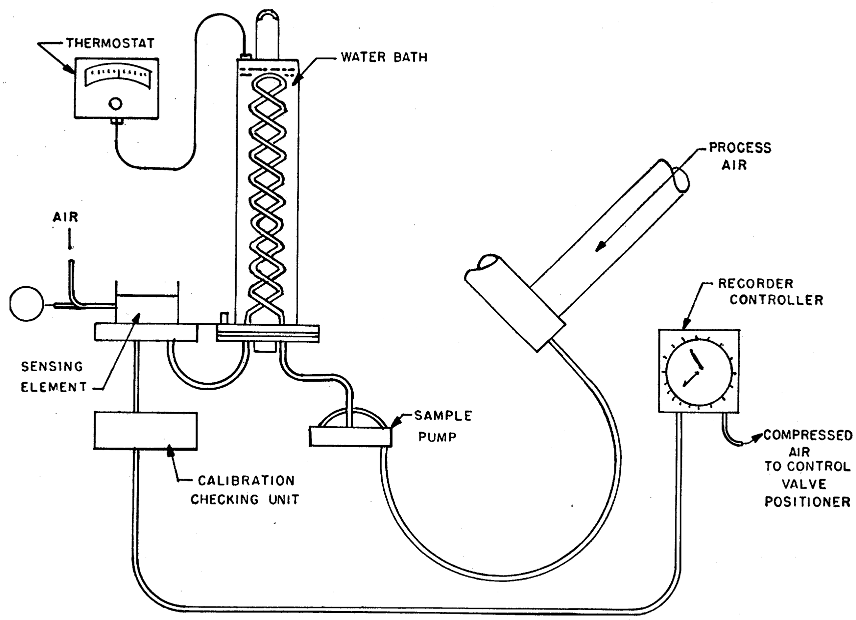

Fig. 2. Dew-point measuring system.

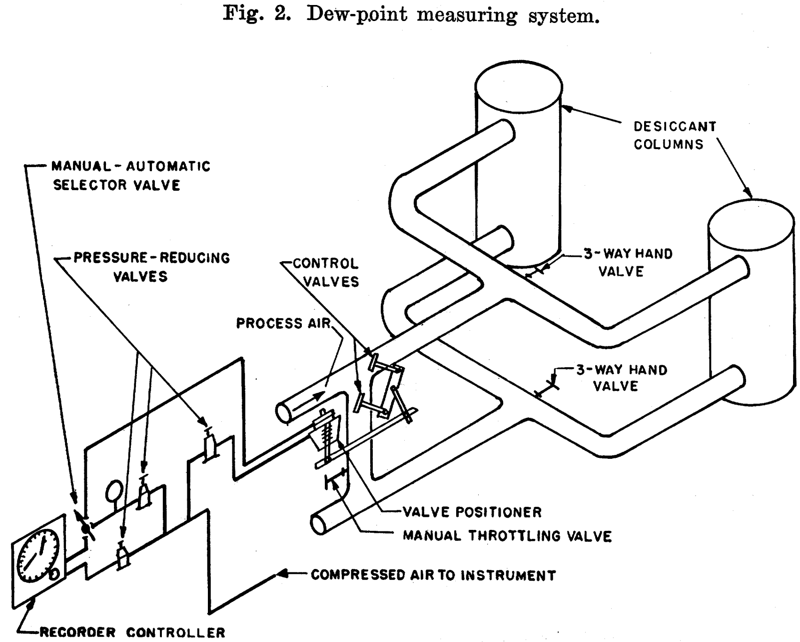

Fig. 3. Dew-point control system.

Fig. 2 gives a schematic of the dew-point measuring system. A sample of air is continuously removed from the process stream by a pump and passed through copper tubing immersed in a water bath to bring the air temperature to 110°F. The air is then passed through the sensing element which, in essence, is a capacitor with alumina as the dielectric. The moisture content of the alumina is a function of the humidity of the air, and the capacitance of the sensing element is a function of the moisture content of the alumina. Thus, the signal from the sensing element to the control instrument depends on the dew-point temperature of the process air.

Fig. 3 gives a schematic of the dew-point control system. The control valves are positioned pneumatically by either an automatic operation through the recorder-controller or a manual operation by-passing it. A manually operated throttling valve is provided in the desiccant column by-pass line to add a greater resistance to flow in that line, thus tending to balance the resistance to flow in the desiccant column and giving the control valves greater sensitivity.

The dry-bulb control system is shown schematically in Fig. 4. The refrigeration unit has a compressor rated at 7.5 HP and the unit has a rated capacity of 3.4 tons of refrigeration, cooling 20 gal per min of 38% ethylene glycol solution from 12.7° to 8°F. During the run the temperature of the cooling coil must be greater than the dew-point temperature of the process air stream. Hence, a temperature control mechanism for the ethylene glycol solution is provided. This temperature control is done automatically by recycling part of the ethylene glycol solution back to the coil along with some colder ethylene glycol from the refrigeration unit.

Air rate is measured by a flow element connected to an inclined manometer.

The dryer is shown in cross-section in Fig. 5. It is essentially an inner shell of 18 gage stainless steel sheet with an outer shell of 18 gage aluminum sheet. The shells are separated by a 3 in. thickness of insulation. There is a double window in each door of

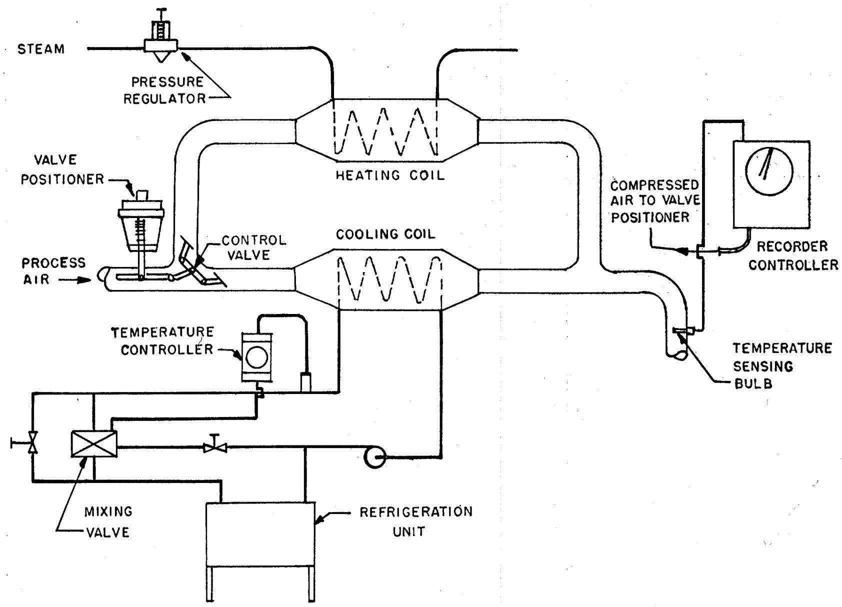

Fig. 4. Dry-bulb control system.

Table 1. Summary of performance test results.

Max. evap. rate (lb/min)	0.33	0.04	0.30	......	......
Dry-bulb control temp. (°F)	160	25	160	160	87
Dry bulb variation (°F)	159–162	24–25	158–162	160–161	None
Dew-point control temp. (°F)	12½	None	72	72	16
Dew-point variation (°F)	11½–14	—68– —81[1]	71–74	71–74	16–17
Air rate (SCFM)	300	300	300	100	100

[1] Dew-point temperature measured with a Type 7000 U "Dew Pointer," Alnor Instrument Company, Chicago, Ill.

½ in. plexiglas separated by a 1¼ in. dead air space. Static pressure taps are provided on each side of the dryer above and below the pan shelf. Both the upper and lower chamber have inside dimensions of 2 ft × 2 ft × 2 ft as recommended by Colker (1946) to produce uniformity of airflow through a 1 sq ft drying pan. The drying pan is of 18 gage stainless steel, 6 in. high and 12 in. × 12 in. cross-section. The bottom of the pan is 10-mesh stainless steel screen, wire diameter 0.035 in., open area 42.3%.

PERFORMANCE

A series of tests was carried out to determine the ranges of cycle of the dry-bulb and dew-point automatic control systems under various conditions. A pan of ⅜ in. carrot dice was used to provide the water vapor load for each test. The results of these tests are given in Table 1. They show that both systems performed satisfactorily. The dew-point temperature, however, was usually slow to stabilize automatically. It was found that dew-point stability could be reached rapidly after start-up if manual control was used initially. After a short time the dew-point control could be shifted to automatic. Automatic dry-bulb control was stable at all times.

A test was made using ⅜ in. potato dice to determine if one desiccant column could maintain the dew-point temperature at or below 0°F under the most difficult conditions. Air at 160°F dry-bulb temperature and 300 SCFM was recycled through one desiccant column and the bed of potato dice. The maximum evaporation rate from the potato dice was 0.32 lb/min. The dew-point temperature of the air leaving the column was at or below 0°F during the whole course of the test which lasted for 2½ hr and during which 16.3 lb of water were absorbed by the desiccant from the potato dice.

A series of tests was run to show how well drying data could be reproduced in the apparatus. Peas which had been blanched and frozen were purchased for three of the tests. The peas were graded in the frozen state and stored at 4°F until needed. Grade No. 5 peas for the tests were thawed overnight, scarified and loaded into the drying pan to a depth of 3 in. (11.1 lb). Air rate and relative humidity were kept constant for the three tests at 300 SCFM and 4% respectively. Drying was interrupted periodically to remove the pan from the dryer for weighings.

In preparation for weighing the process air stream was diverted through the lower chamber of the dryer instead of turning off the blower. In this way the control systems were not upset while the drying cycle was interrupted for weighings. Moisture contents were determined on the dry products by the usual vacuum oven technique and from these and the weighings the drying curves in Fig. 6 were calculated. The solid and open geometrical figures of the same type represent the drying data from the two runs caried out at each dry-bulb temperature.

The drying data in Fig. 7 are from "freeze-drying" tests run as above on apple dice. York Imperial apples were peeled, cored, sulfite-dipped, diced to a nominal size of ¾ in. × ½ in. × ⅜ in., redipped in sulfite solution, fines removed, and frozen overnight at 4°F in the drying pan at a depth of 3 in. (10.0 lb). Drying was carried out at 25°F dry-bulb, 2% relative humidity, and 150 SCFM air rate. The

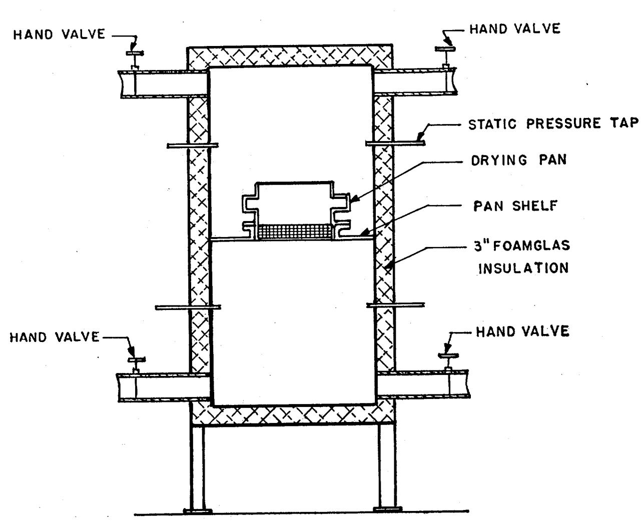

Fig. 5. Experimental dryer.

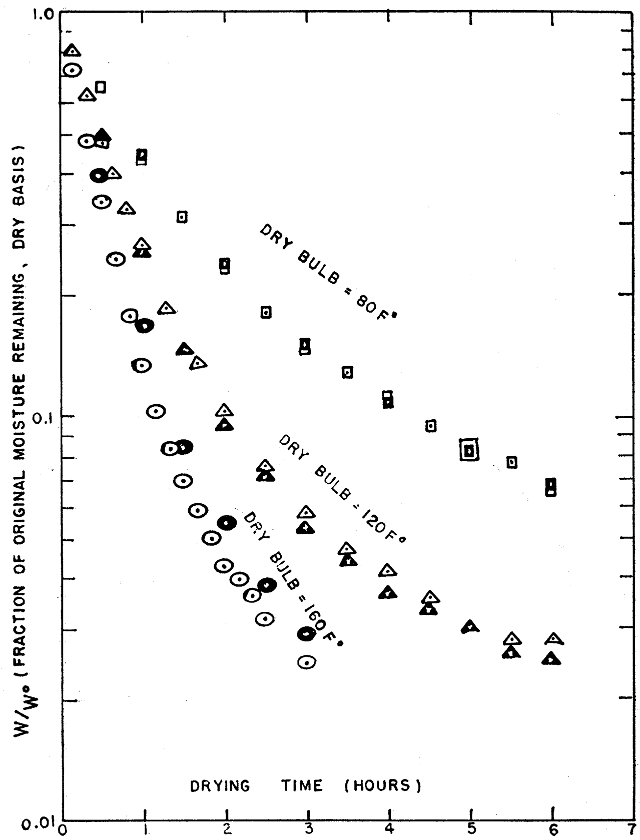

Fig. 6. Drying curves for peas.

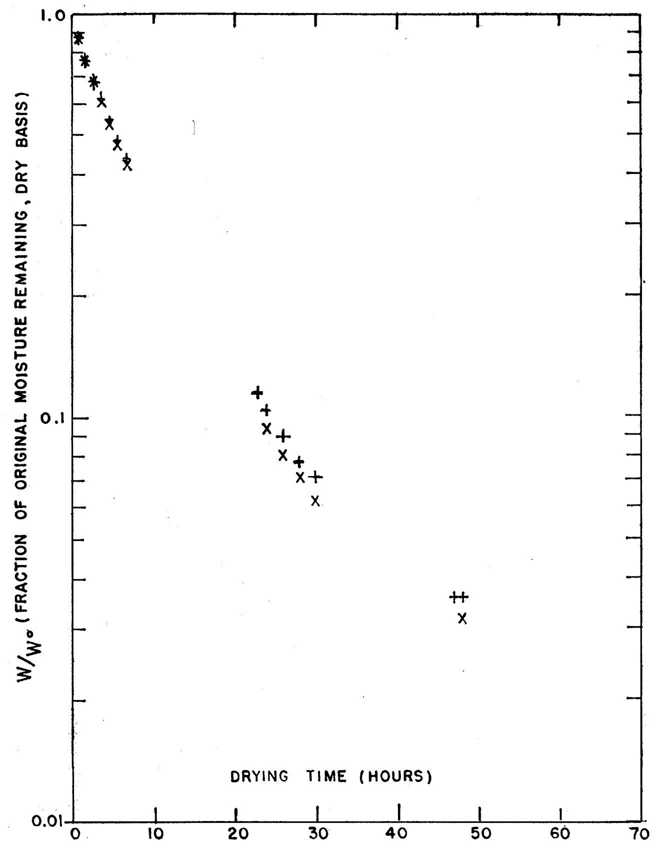

Fig. 7. "Freeze drying" curves for apple dice.

crosses represent data from one run and the "X's" represent data from the duplicate.

The tests on reproducibility reflect not only variability due to the equipment, but also variability due to batch, pre-drying operations, scale, operator, and moisture analysis. In the cases of the tests with peas, variability with respect to time interval between weighings was also introduced.

DISCUSSION

A primary value of this apparatus lies in the fact that it provides means for drying at low temperatures where desiccated air is required. This, in turn, opens up possibilities for preparing unique dehydrated foods. However, the dehydration of most food materials takes place mainly in the falling rate period, during which the diffusivity of water decreases exponentially with decreasing product temperature. Thus, complete drying at low temperatures appears to be impractical due to the length of the drying cycle. (See, for instance, Figure 7, which shows that after 48 hours of drying with desiccated air at 25°F the moisture content of the apple dice still stood at about 16%.) On the other hand, it may be feasible to use low temperature air during part of a drying cycle, particularly if its use yields a product of better quality.

Determining product weight during air drying without introducing some error into the drying curve is a problem that has never been completely solved. New experimental freeze dryers operating under vacuum contain balances that can be used to continuously measure the weight of the product without interrupting the drying cycle, but this is not possible in through-circulation air drying for obvious reasons. To obtain product weights for drying curves, the drying cycle must be interrupted, and in so doing a potential error in the drying curve is introduced because the product may very well change its temperature and moisture content when it is taken from the drying air stream.

This dilemma was considered carefully during the design of the present apparatus and it was decided to remove the tray periodically for external weighing rather than to build an internal weighing system into the dryer. The temperature of the product will change when it is removed from the drying air stream, whether the product is taken from the dryer or not. External weighing is simple and can be accomplished in 15 to 30 seconds. In addition, the weighing step introduces a potential error in the drying curve whether the weighing be done externally or internally. The magnitude of that error can be evaluated through proper experimental design.

With the exception of the dryer, which was designed by us and built in our shops, all parts of this experimental apparatus were made by well-known manufacturers and are readily available on the open market. These parts were sized, brought together, and adjusted to meet our specifications by a contractor. For further details on the apparatus as a whole or any part of it, inquiry may be made of the authors.

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